

AD No.                     
DDC FILE COPY

416014

762 1<sup>1</sup>) **ROCKETDYN**  
A DIVISION OF NORTH AMERICAN AVIATION INC

63-4-3

1

AFOSR-TN-59-878

(6) 7.11.64  
SUMMARY OF EXPERIMENTAL, [ON ROCKET PROGRAM.

**FOR THE PERIOD**

Left fr. 1 MAY 1958

30 APPENDIX

10/284.

(13:11)

17 AM

30/11

三

## ROCKET DYN E

A DIVISION OF NORTH AMERICAN AVIATION, INC.

CONTRACT AF 40(638)-351

(16) PROJECT 3750

(1) MAY 1959,

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

1101A

PROPELLION RESEARCH DIVISION,

WASHINGTON 25, D. C.

11. 3. 60

ROCKETDYNE  
A DIVISION OF NORTH AMERICAN AVIATION INC

---

FOREWORD

This report is submitted in fulfillment of the requirements of Contract AF49(638)-351, the experimental ion rocket program being conducted by Rocketdyne, a Division of North American Aviation, Inc. The program is sponsored by Air Force Office of Scientific Research, Propulsion Research Division. This report was reviewed and approved by R. H. Boden, Program Engineer.

Principal technical contributors include:  
A. T. Forrester, R. C. Speiser, D. J. Kerrisk,  
T. A. Coulas, P. E. Schumacher, J. Hyman,  
M. L. Swift, and A. W. Deveraux. The Technical Editor was E. W. Cornell.

~~RESEARCH STUDY NO. 3~~  
A STUDY OF THE BASIC PRINCIPLES OF ELECTRICAL PROPULSION

~~ABSTRACT~~

The purpose of this program is to gain an understanding of basic electrical propulsion principles, propellant properties, and ionization and acceleration techniques. Experimental studies were performed on contact ionization ion sources, ion acceleration, and ion beam neutralization. Small research-type devices were successfully operated in ion motor configurations to verify theoretical analysis and to integrate experimental tests on components. The report discusses two types of vacuum systems: a bell jar, and a small steel tank. The tank operation proved more versatile, and two working variations of the device were built and tested. Instrumentation, fabrication, and neutralization techniques are described, and future work is outlined.

**ROCKETDYNES**  
A DIVISION OF NORTH AMERICAN AVIATION INC

---

**CONTENTS**

<b>Foreword</b>	ii
<b>Abstract</b>	iii
<b>Introduction</b>	1
<b>Discussion</b>	4
Bell Jar Operations	4
Eight-In. Tank Operations	9
Eight-In. Tank Instrumentation	22
Fabrication Techniques	23
Neutralization	24
<b>Future Work</b>	27
<b>References</b>	28

---

ILLUSTRATIONS

Figure:

1. Bell Jar Apparatus with Cover Removed . . . . .	5
2. Schematic of Bell Jar Apparatus . . . . .	6
3. Cesium Ion Current from Graphite Ionizer . . . . .	7
4. Cesium Ion Currents from Graphite and Tungsten Ionizers . . . . .	8
5. Tank System . . . . .	10
6. Schematic of 8 Inch Tank . . . . .	11
7. SAMMY Device . . . . .	12
8. Schematic of SAMMY Device . . . . .	13
9. Modified CHARLIE Device . . . . .	15
10. Schematic of Modified CHARLIE Device . . . . .	16
11. Various Current-Voltage Characteristics . . . . .	17
12. Accelerating System Characteristics . . . . .	18
13. Collector Current vs Collector Bias . . . . .	20
14. Oscillation Data . . . . .	21
15. Thrust Measurement Device . . . . .	24
16. Schematic of Thrust Measurement Device . . . . .	25

#### INTRODUCTION

During the contract year, effort was devoted exclusively to contact (surface) ionization sources utilizing cesium as an expellant. Analytical considerations indicated the suitability of this type of system for ion propulsion. Calculations of the interaction between ions and neutral atoms dictated that the cesium be delivered to the ionizer surface by diffusion through a porous material. The several ion devices utilized in the experimental program were of this type.

Delivery of cesium to an ionizer surface from the downstream side is not feasible because of the excessive scattering of the beam and the voltage breakdown problems that would occur due to the relatively high delivery pressure necessary. There would also be excessive loss of un-ionized propellant. Cesium delivery must therefore be from behind the ionizer. The requirement of very low neutral-to-ion efflux ratio from the ionizer determines the use of a very fine structure ionizer in the following manner:

Consider an ionizer having raised and recessed areas, the raised areas being closer to the accelerating electrode. The buildup of space charge would prevent the emission of ions from the recessed regions because the fields would not penetrate into those areas. These areas would then contribute only neutral cesium atoms to the total efflux. Because these areas are upstream of the ion-emitting areas, the cesium concentration would be higher, and too high a percentage of un-ionized propellant would result.

In the case of delivery of cesium by diffusion through a porous material, calculations were made of ion and neutral atom efflux rates. From data presented in Ref. 1 it has been determined that to prevent the excessive

evaporation of neutrals from a tungsten ionizer, it is necessary to maintain the coverage of the surface to less than 4 percent of a complete monatomic layer. At temperatures of 1600 K, very large ion currents ( $80 \text{ ma/cm}^2$ ) can be obtained with a coverage of only 1/2 percent. The problem was attacked by calculating whether diffusion of cesium over the surface of the tungsten could deliver adequate cesium to the exposed surfaces from the deeper-lying surfaces if the coverage difference is only 3.5 percent.

The rate at which cesium will be delivered to the 1/2 percent covered area from the 4 percent covered area depends on the surface diffusion constant and on the geometric relationship of the two areas. A diffusion constant extrapolated to 1600 K from lower temperature values of Taylor and Langmuir (Ref. 1) for cesium and tungsten were used. It was further assumed (for simplicity) that the surface had the form of a checkerboard with red squares having 1/2 percent coverage and raised above the black squares (which had 4 percent coverage) by an amount equal to the side of a square. For this situation, the delivery of cesium at a rate adequate to provide  $80 \text{ ma/cm}^2$  from the red squares requires that the square size be not more than  $10^{-4} \text{ cm}$ . If the assumed surface is regarded as an approximation to the surface of a porous material,  $10^{-4} \text{ cm}$  can be specified as a maximum pore size and pore spacing. This size appears to be easily achievable with available techniques. Further calculations indicated that, for a 1/16 in. thickness, this pore size will provide an adequate throughput of cesium with a pressure difference of the order of 1 mm of mercury. To achieve this pressure, it will be necessary to maintain the cesium reservoir at a temperature of 273 C. The average ion current density from the ionizer under these conditions would be  $40 \text{ ma/cm}^2$ .

Assuming that the porous ionizer radiates as a black body, the power required for the ionizer heating was compared with power which must be used to accelerate the ions. The black body radiation is actually an upper limit to the power radiated because the emissivity of the surface must be less than unity, and because the accelerator will serve as a heat shield. This calculated loss may well be as much as five times too high. At 1200 K, the black body radiation is  $12 \text{ w/cm}^2$ . If we accelerate the available ion current ( $0.4 \text{ ma/cm}^2$ ) through 15,000 v,  $6 \text{ w/cm}^2$  is delivered to the beam. At higher temperatures, the situation becomes much more favorable. At 1500 K, black body radiation increases to  $29 \text{ w/cm}^2$ , but if the available ion current ( $28 \text{ ma/cm}^2$ ) is accelerated through 15,000 v, the power into the ion beam is  $420 \text{ w/cm}^2$ .

Considerations of electron bombardment of the ionizer by electrons produced by photoelectric emission, thermionic emission, or high field effects at the accelerating electrode, indicated that these phenomena could be negligible.

Due to the low specific charge of cesium, direct electrostatic acceleration was found most suitable in the early experiments. This was later modified to an accelerate-decelerate system in anticipation of neutralization of the ion beam with electron emitters near the exit aperture. The accelerate-decelerate system prevents the beam neutralizing electrons from getting back to the ionizer and also allows somewhat higher space-charge, limited-current densities in the acceleration gap.

## DISCUSSION

Initial experimentation was performed in a bell jar vacuum system which performed satisfactorily for simple configurations at moderate voltages, but proved inconvenient for more advanced devices. In February 1959, tests were started in the more versatile 8-in. tank facility and the tests have continued to the present.

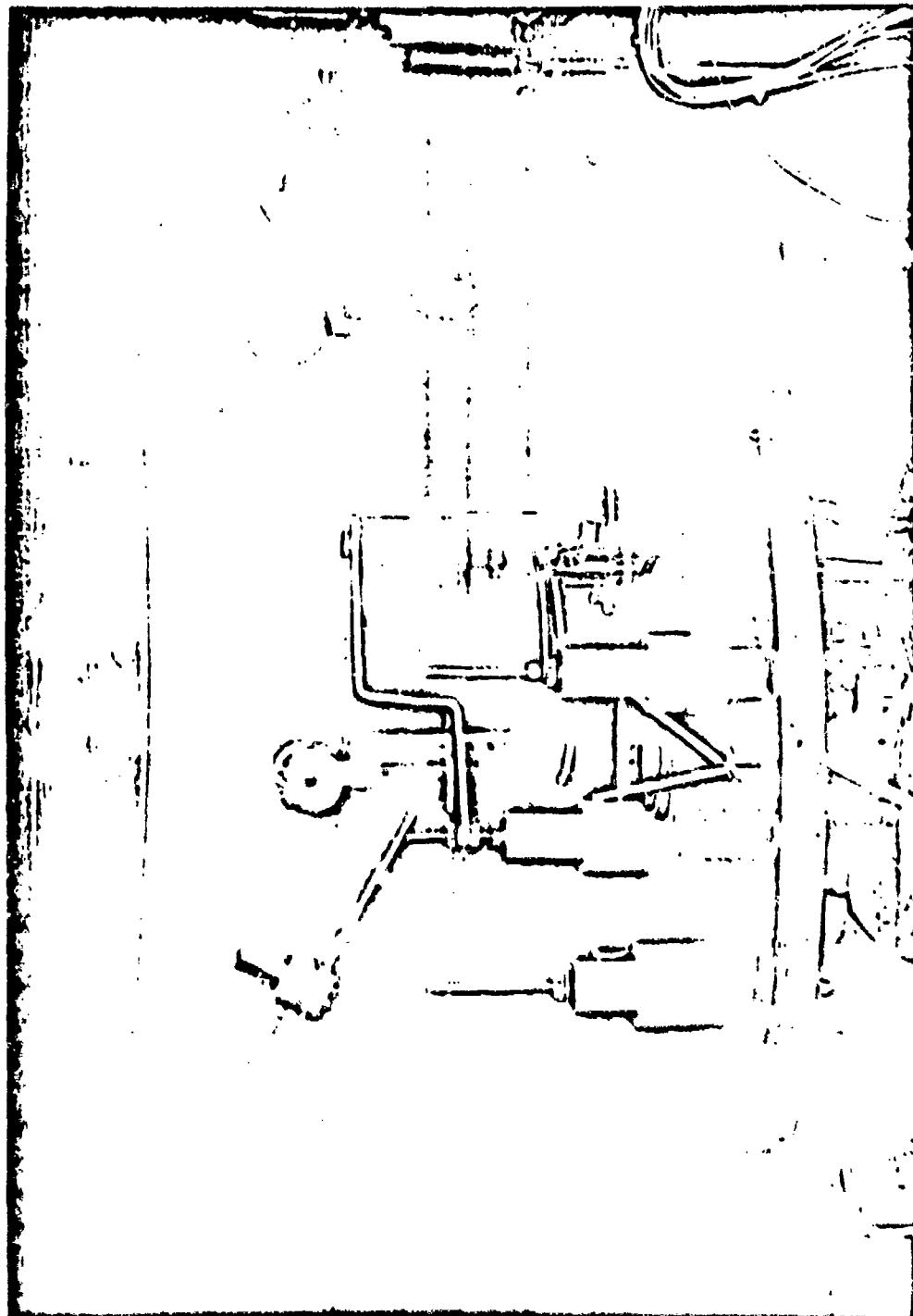
### BELL JAR OPERATIONS

In the first surface ionization tests, cesium was diffused through a 1/8-in.-thick, 1/2-in.-dia, porous graphite ionizer in the apparatus in Fig. 1 and 2. A porous tungsten ionizer was also used in this configuration. Representative data are presented in Fig. 3 and 4.

It may be noted that the reservoir temperatures recorded are much too low to provide sufficient cesium vapor pressure and flowrate to sustain the currents measured. The thermal insulation of the reservoir from the ionizer region was not adequate and the cesium was heated by radiation and conduction down the delivery tube heating the surface of the cesium in the reservoir. This was corrected in later tests by the inclusion of radiation shielding inside thinner-walled delivery tubes.

The shapes of the curves of Fig. 3 are as expected for space-charge-limited and temperature-limited operation. The current varies as  $V^{1/2}$  for high ionizer temperatures and low accelerating voltages. The gradual breaks in the curves to temperature-limited values are due to the fact that the current can be space charge limited in the center of the aperture and temperature limited in the peripheral area. Since operation at higher temperatures was still partially space charge limited, it was decided to go to higher current density handling capacity configurations.

**ROCKET DYNE**  
A DIVISION OF NORTH AMERICAN AVIATION INC



1242-8/15/8-SIA

Figure 1. Bell Jar Apparatus with Cover Removed

II-1763

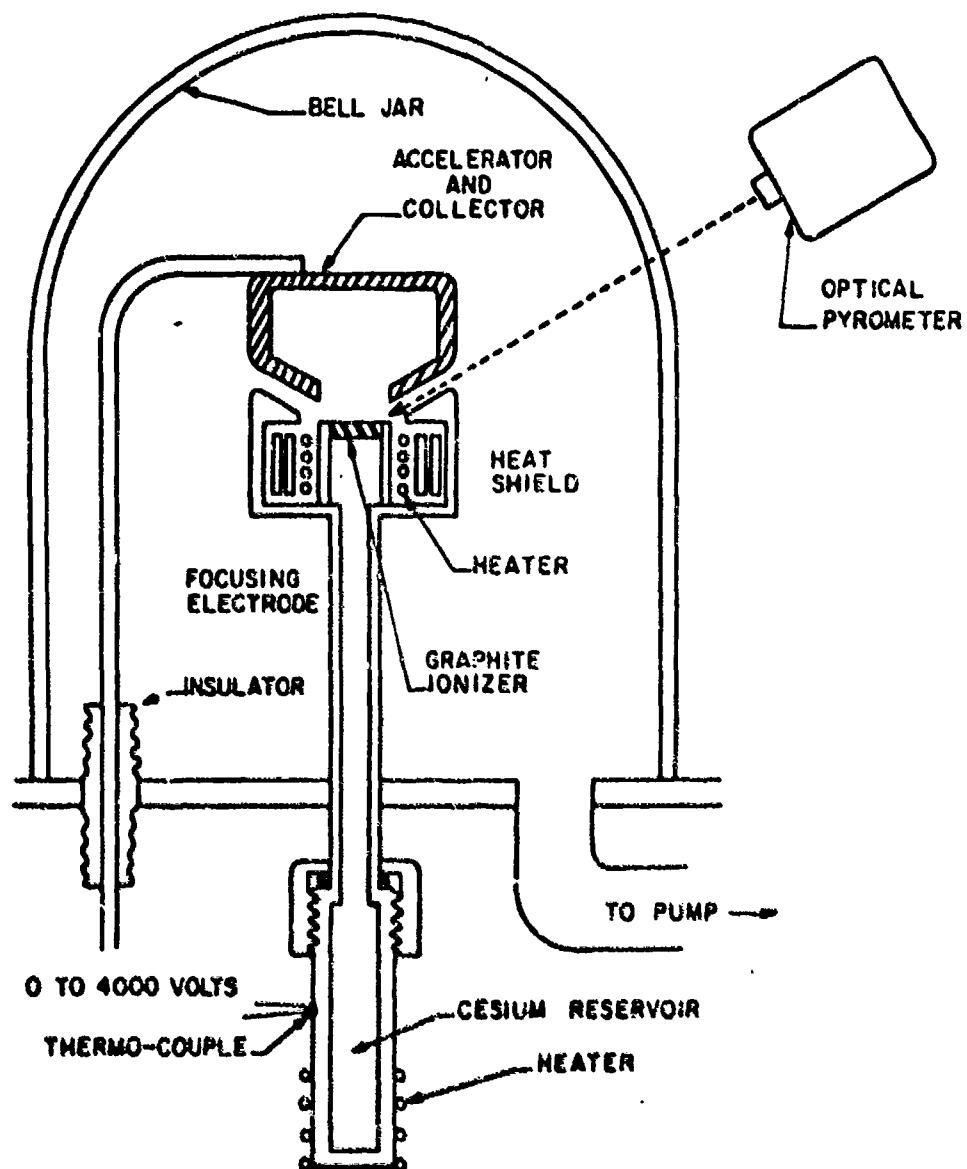


Figure 2. Schematic of Bell Jar Apparatus

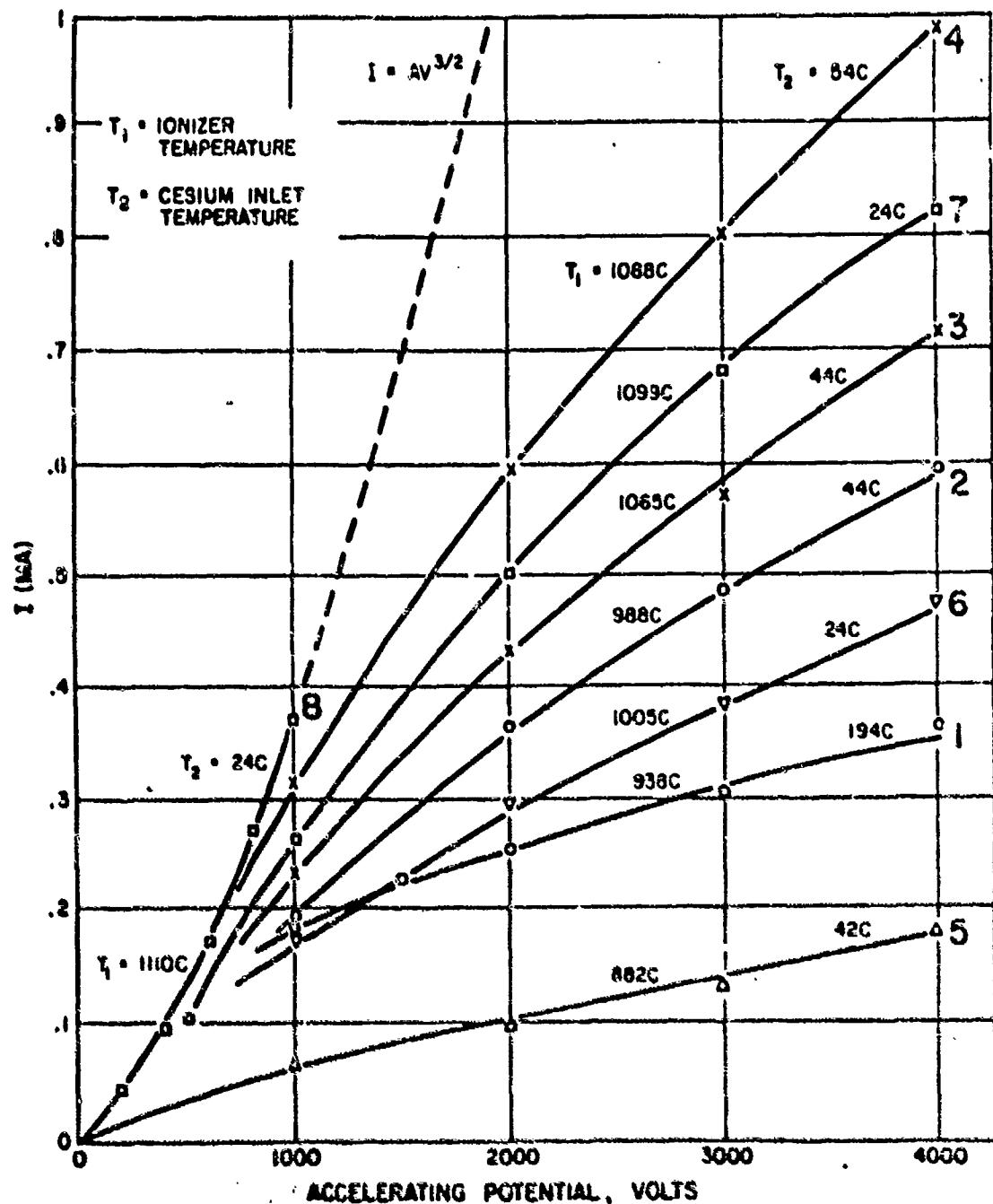


Figure 3. Cesium Ion Current From Graphite Ionizer

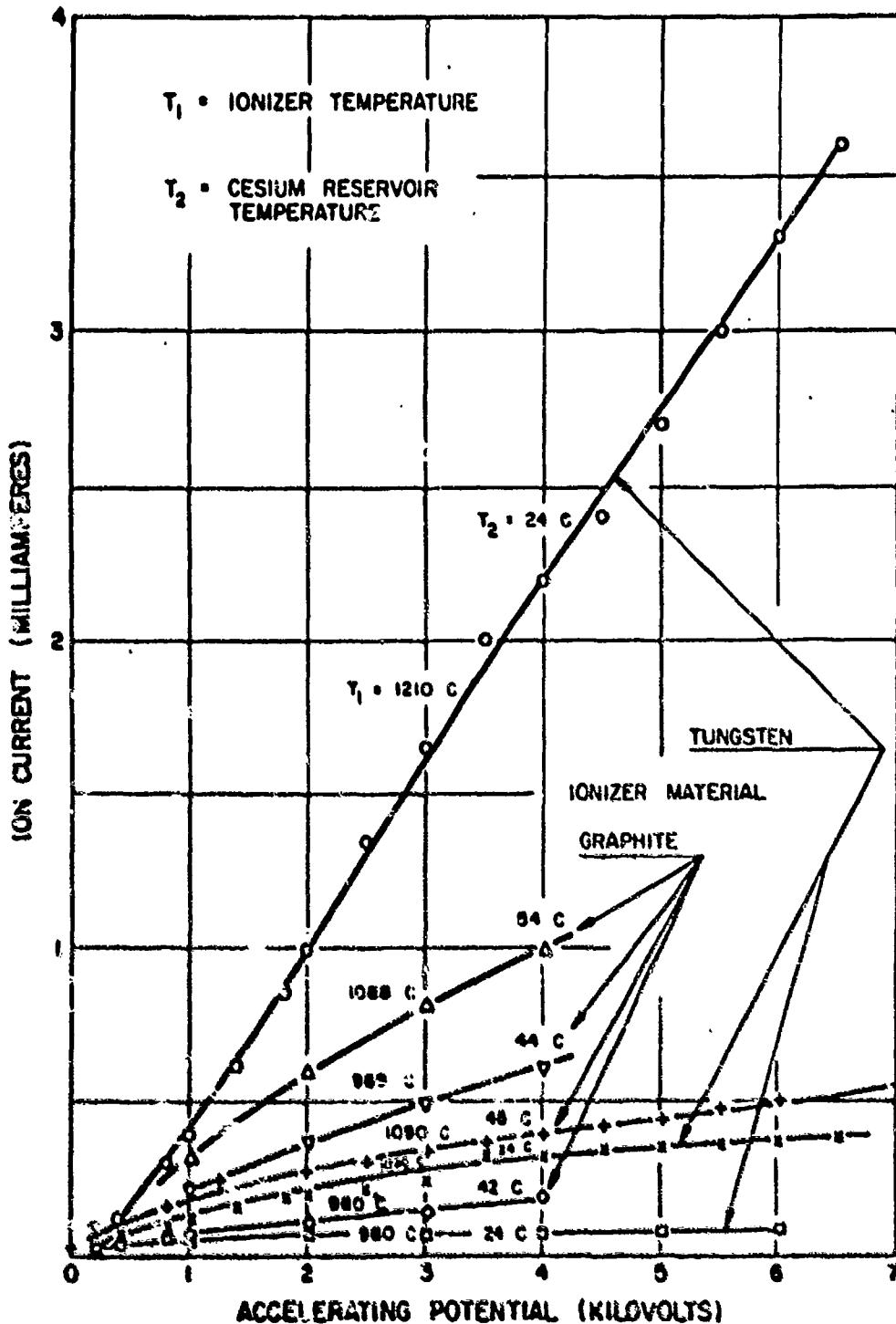


Figure 4. Cesium Ion Currents From Graphite and Tungsten Ionizers  
R-1761

Accordingly, a slit-shaped source 1/8 in. wide and 2 in. long utilizing a porous nickel ionizer was tested. Operation was not successful, and later examination disclosed that the pores had closed. Another nickel ionizer was tested with similar results. The reason for the loss of porosity was not clear, and the use of nickel as an ionizer material was discontinued.

#### EIGHT-IN. TANK OPERATIONS

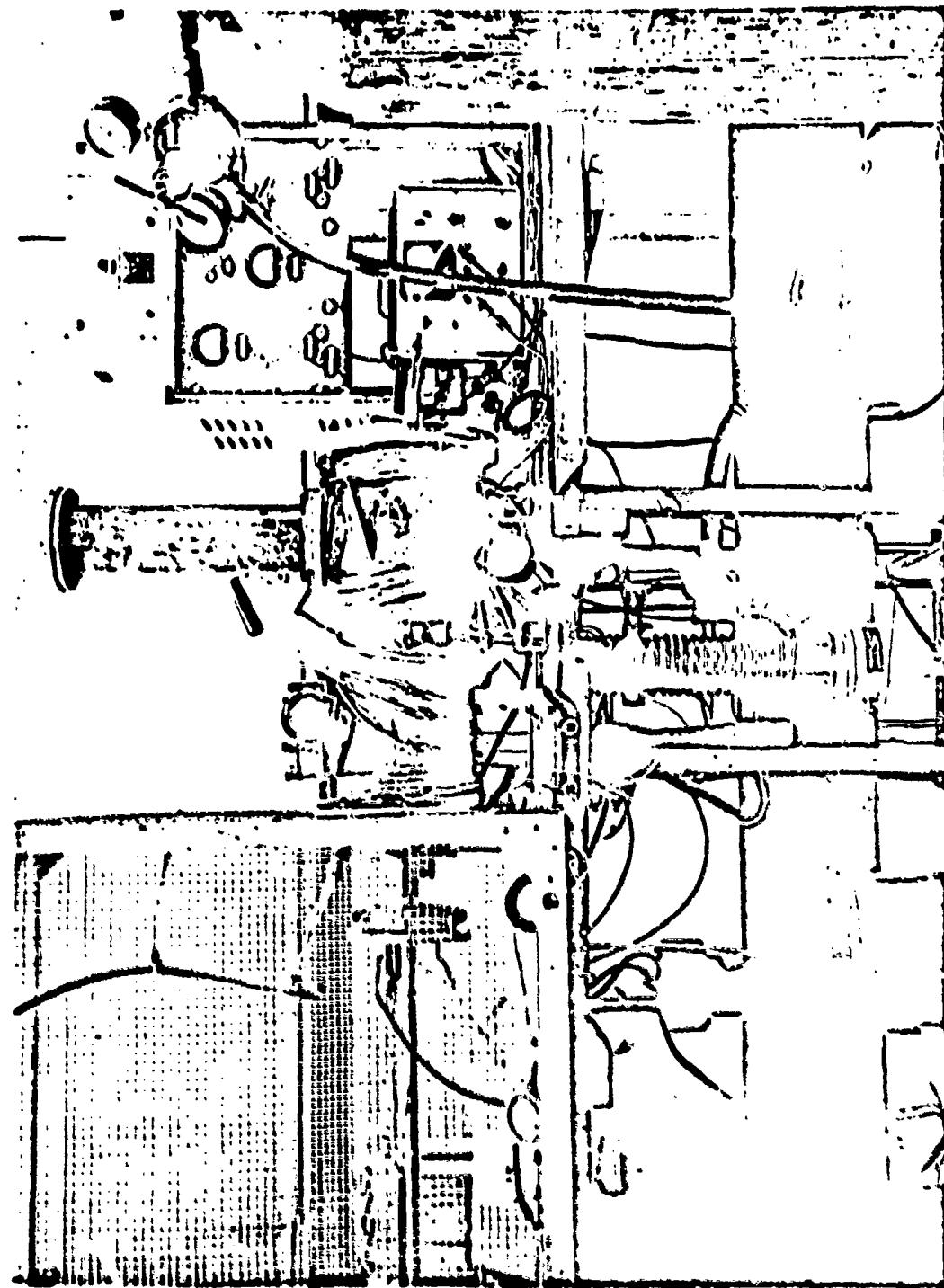
The vacuum tank is a stainless steel cylinder 8 in. in diameter and 2 ft long (Fig. 5 and 6). The tank is evacuated through a 4-in. gate valve and a liquid nitrogen cold trap region by a 300 liter/sec, three-stage fractionating, oil diffusion pump.

The diffusion pump has a water-cooled baffle at its inlet and is backed by a 7-liter/sec, two-stage mechanical pump also used for roughing. The diffusion pump is water cooled and it has an auxiliary cooling coil on the boiler to allow fast cooling on shutdown. Its speed drops to 100 liter/sec at  $10^{-6}$  mm Hg. To provide for both monitoring of pressure and trouble shooting, there are ion gages in the main tank and in the liquid nitrogen trap region.

Both end plates of the tank are removable, and ion sources and collectors are directly mounted on end plates which can then be attached as desired. In addition there are three, 4-in.-dia ports for viewing or instrumentation. Two are at 90 deg and 6 in. from the ends of the tank, and the third is in the middle of the tank at a 45 deg angle. The tank is wrapped with cooling lines to increase its power handling capacity.

Experimentation was switched to the 8-in. tank as soon as it was operable. The first device operated was designated SAVIT (Fig. 7 and 8). It

**ROCKETDYNE**  
A DIVISION OF NORTH AMERICAN AVIATION INC



R-1763

10

Figure 5. Tank System

1229-4/13/59-SLJ

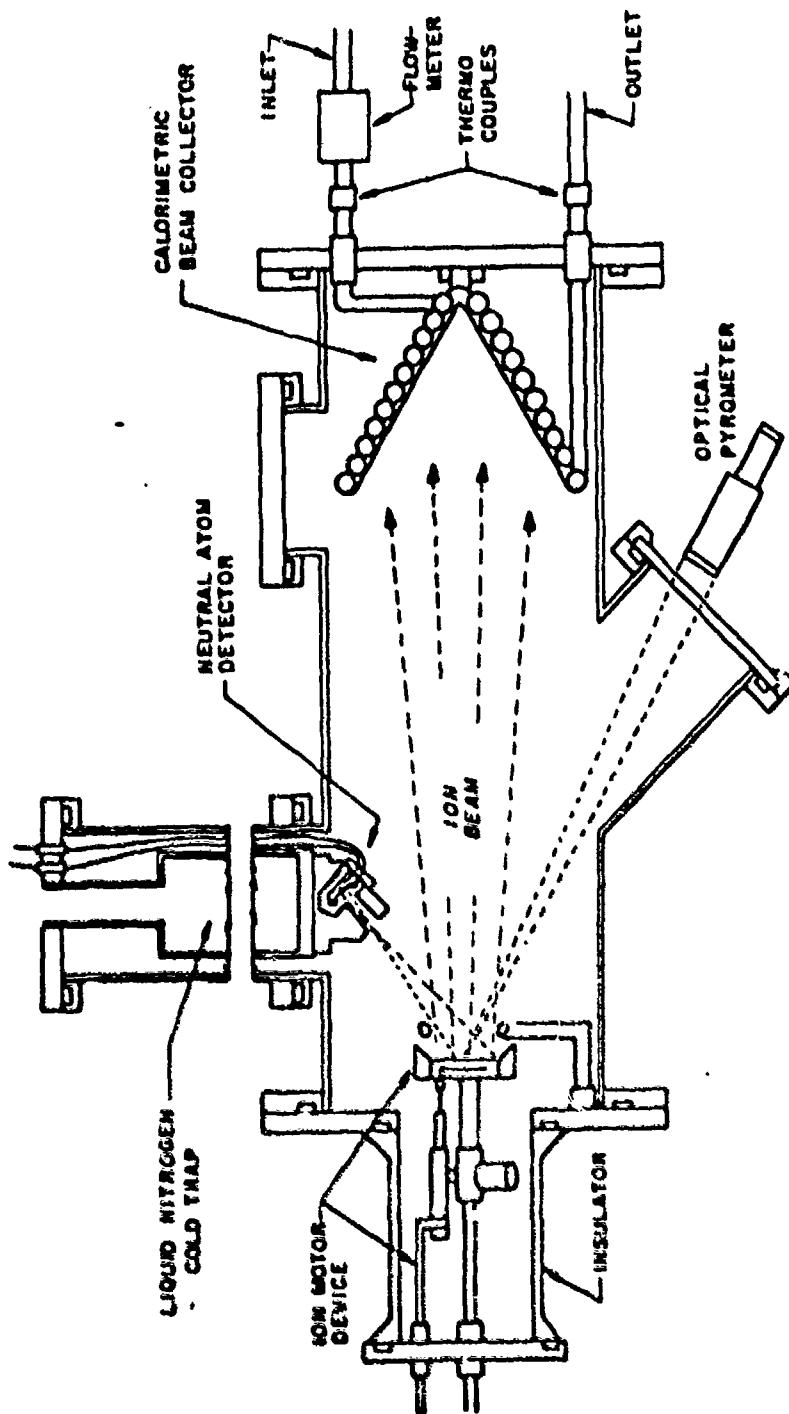
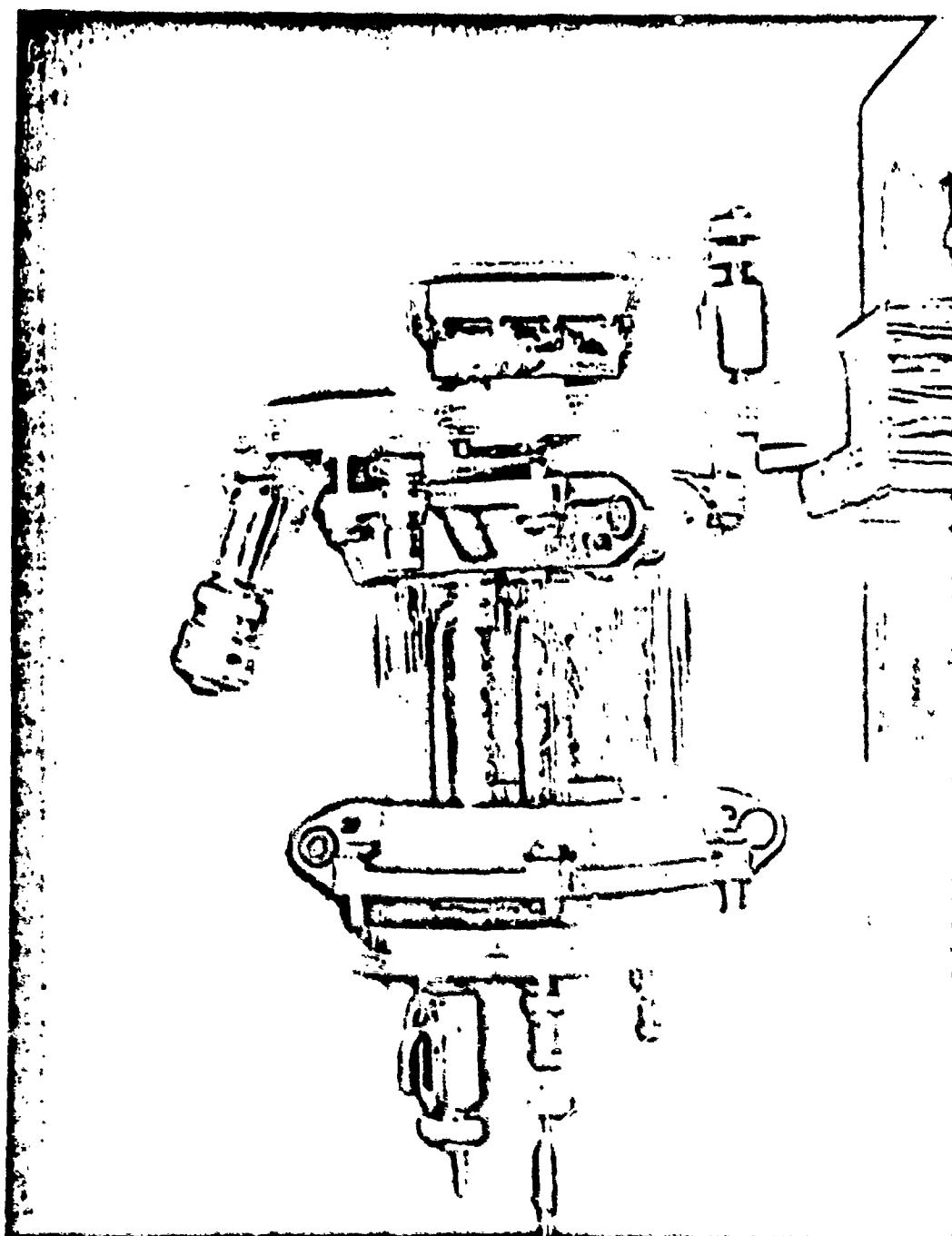


Figure 6. Schematic of 8 Inch Tank

**ROCKETDYNE**  
A DIVISION OF NORTH AMERICAN AVIATION INC



1226-2/6/59-SUA

Figure 7. SAWY Device

R-1763

19

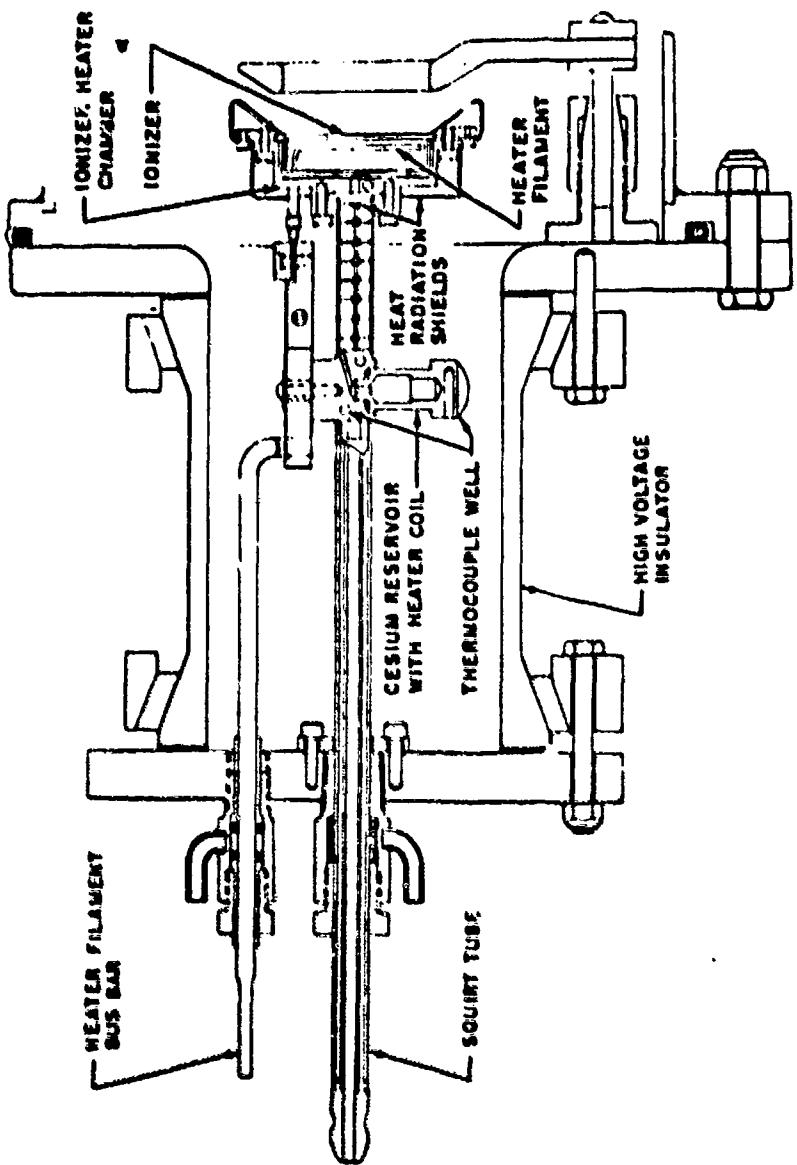


Figure 8. Schematic of SAVAN Device

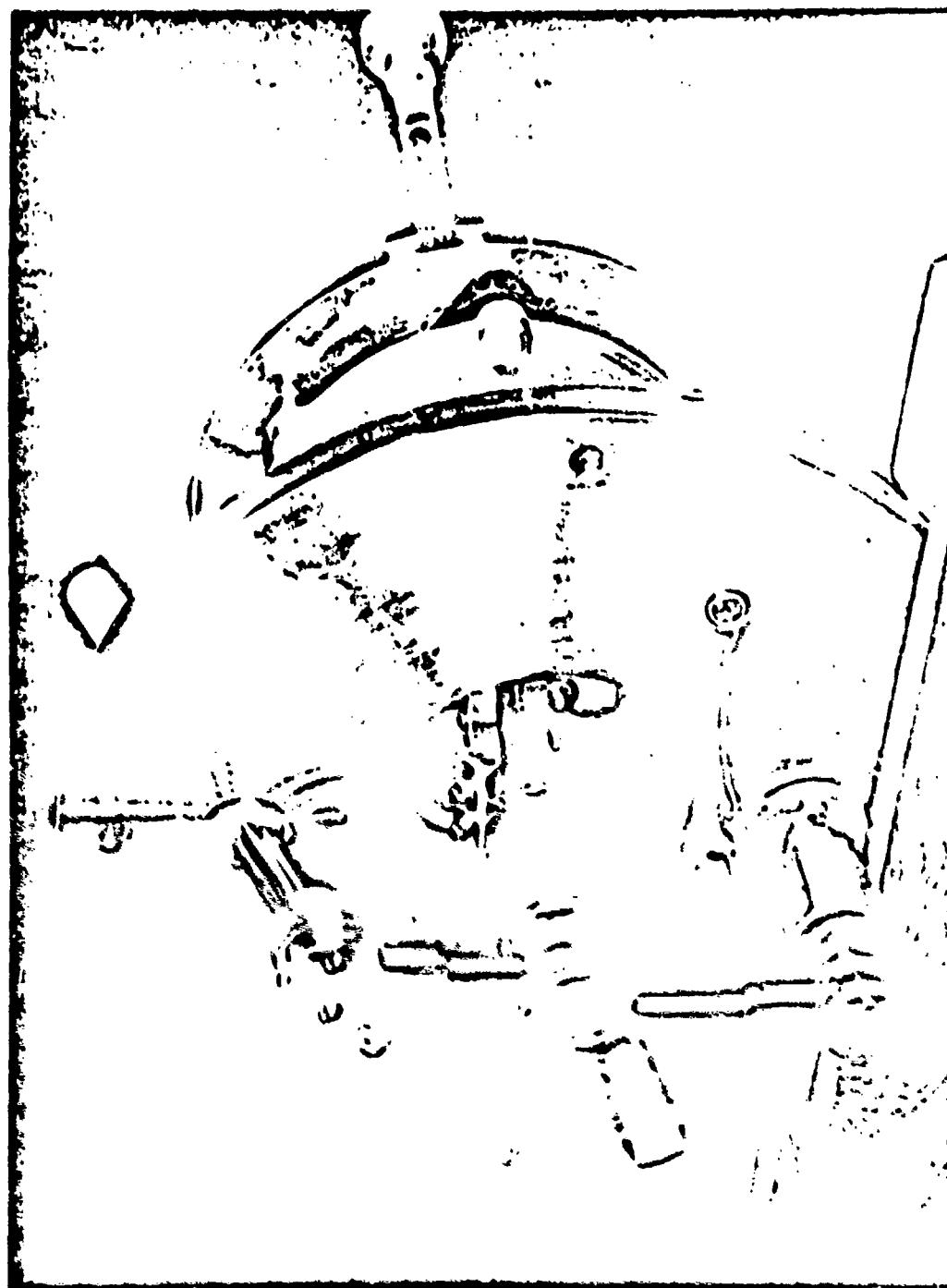
featured a 1/2-in.-wide by 2-in.-long graphite ionizer clamped to a molybdenum box with a platinum gasket. The heater was a 0.060-in.-dia tungsten, hairpin filament mounted inside the box. A heater on the reservoir assembly and a squirt tube on the vaporizer block allowed temperature control of the cesium delivery pressure. The whole source was operated at high positive voltage and insulated by the use of a section of pyrex pipe as the mounting system.

The accelerate-decelerate configuration was used in this and succeeding runs. Several partially successful runs were made with ion currents up to 6.5 ma being measured at the collector. The graphite ionizer had to be replaced due to cracking of the graphite. This was attributed to an interstitial soaking up of the cesium by the graphite with consequent swelling and cracking. The use of graphite has, for the time being, been abandoned.

It was decided early that the temperature controlled cesium delivery system did not afford fine enough control, and a second device, designated CHARLIE, was developed. CHARLIE featured a needle valve in the cesium supply line. With this source, a porous tungsten ionizer was used, and because of fabrication difficulties, initial running was carried out with a circular geometry. The ionizer was 3/16 in. in diameter and welded into the end of a molybdenum tube with an external heater filament (Fig. 9 and 10).

The CHARLIE unit provided data from several good tests. Some representative data is presented in Fig. 11 and 12. Figure 11 shows the variation of the collector and other currents with the potential of the ionizer-field shaping electrode assembly ( $\Phi_p$ ). The accelerating electrode ( $\Phi_A$ ) was held at 2.8 kv negative potential. Some of the total current from the ionizer was intercepted by the accelerating electrode and the ground electrode--the latter dropping to zero as  $\Phi_p$  was increased. The current intercepted by the accelerating electrode passes through a minimum as  $\Phi_p$  increases, indicating

**ROCKETDYNE**  
A DIVISION OF NORTH AMERICAN AVIATION, INC.



PPX-26

Figure 9. Modified CHARLIE Device

R-1763

15

ROCKETDYNE  
A DIVISION OF NORTH AMERICAN AVIATION, INC.

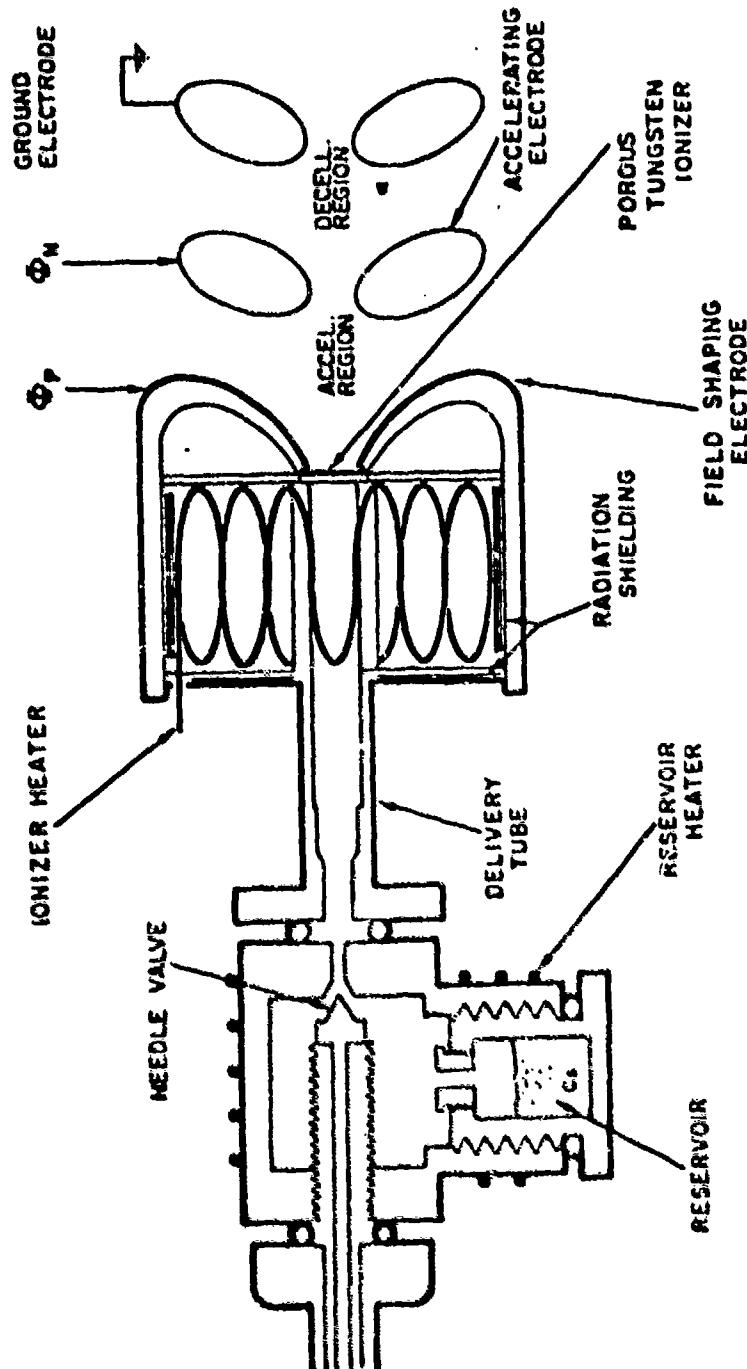


Figure 10. Schematic of Modified CHARLIE Device

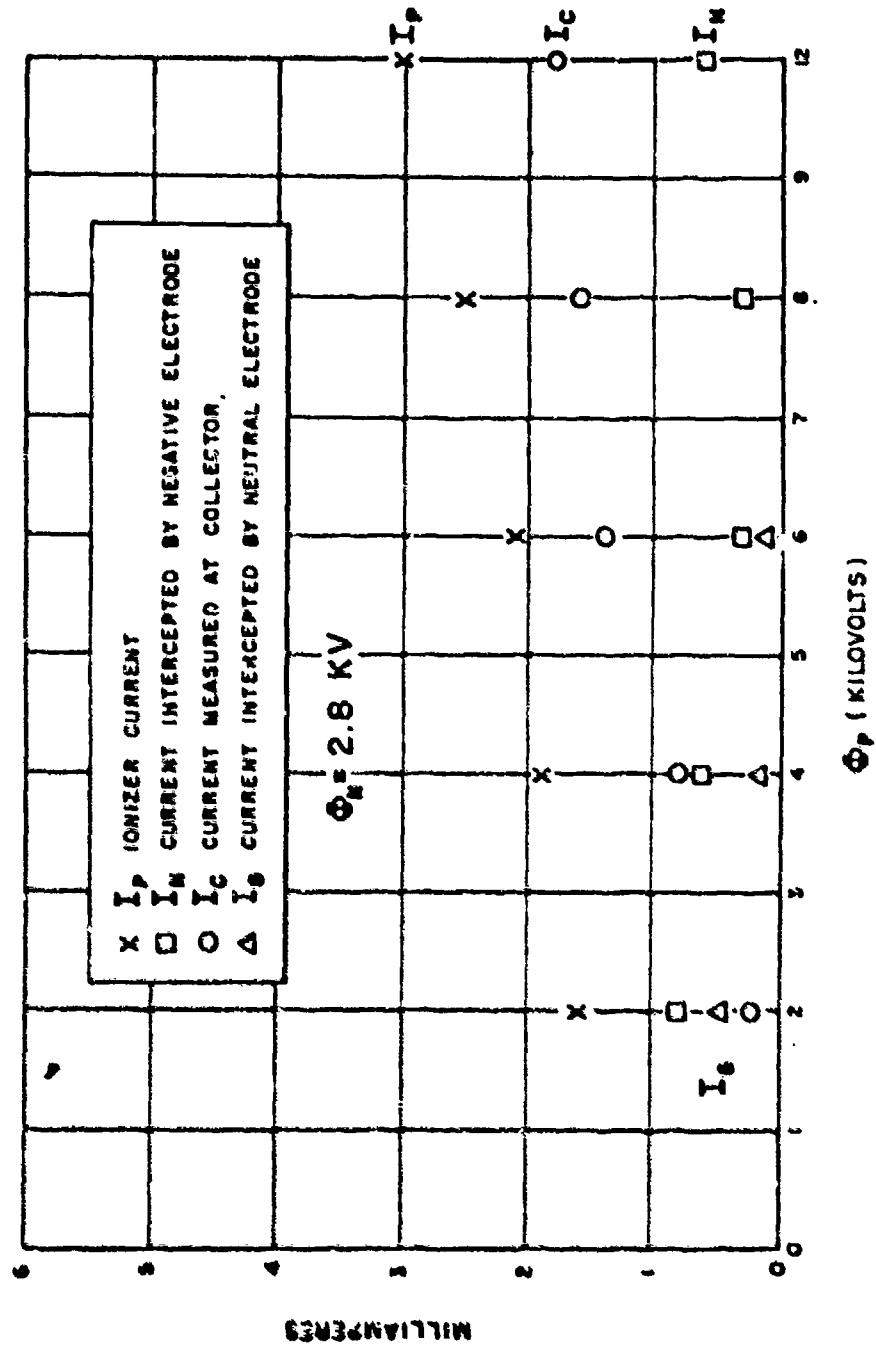


Figure 11. Various Current-Voltage Characteristics

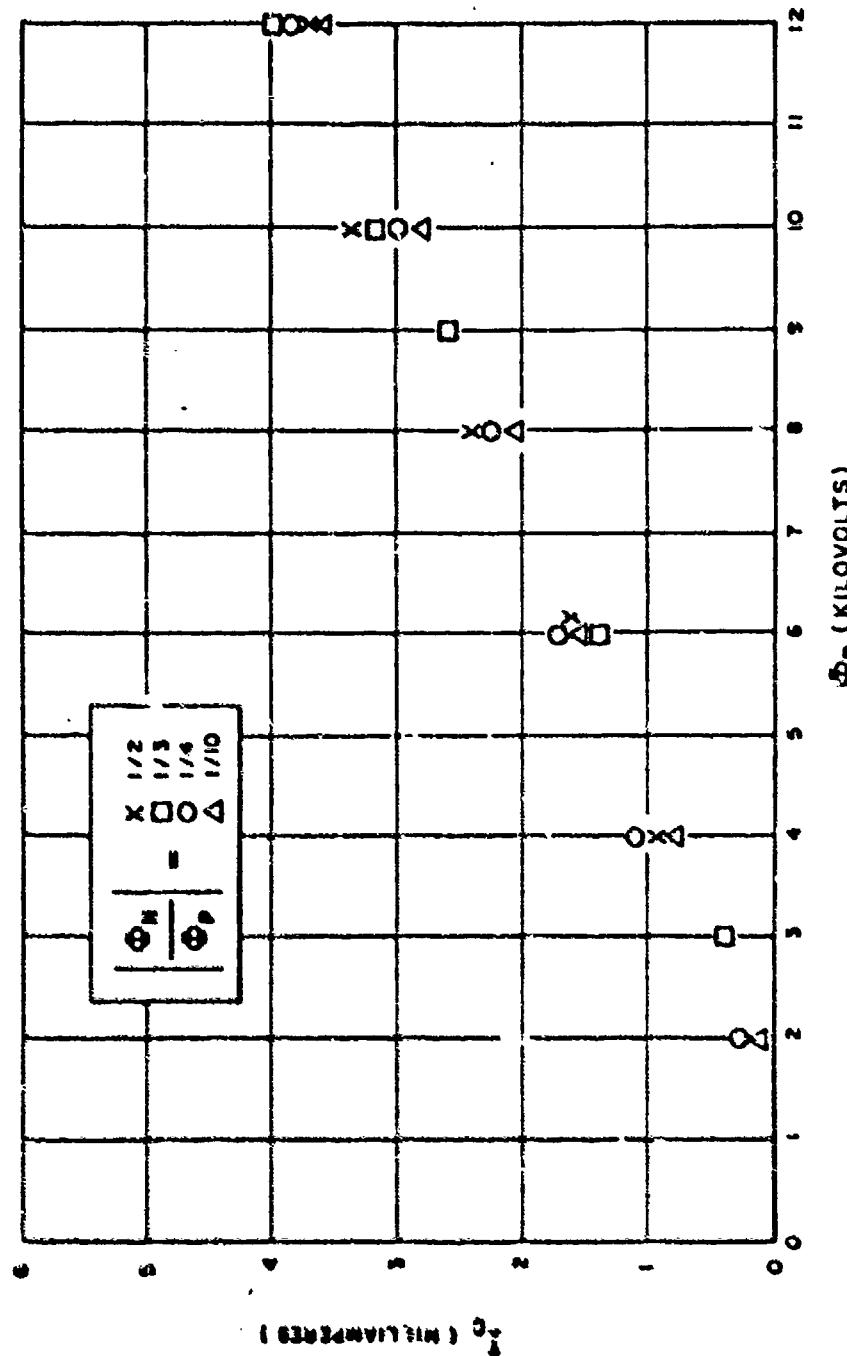


Figure 12. Accelerating System Characteristics

optimum focusing at the point for the fixed  $\Phi_N$ . By this type of test the focusing properties of the accelerate-decelerate system can be determined. Figure 12 shows the variation of the collected ion beam current with  $\Phi_p$  with fixed ratios of  $\Phi_N$  to  $\Phi_p$  as parameters. This type of test also helps determine the properties of the accelerate-decelerate system.

The 4-ma currents obtained correspond to current densities of  $30 \text{ ma/cm}^2$  at an ionizer temperature of about 1500 K. This current density is several times that needed for efficient operation of ion motors at that temperature. The 12-kv net acceleration potential corresponds to an exit velocity of  $1.3 \times 10^7 \text{ cm/sec}$  giving a specific impulse of 13,000 sec.

Small biasing voltages on the collector caused large changes in the measured collector current as shown in Fig. 13. This is a photograph of an oscilloscope trace with current as ordinate and collector biasing voltage as abscissa. The current varied from 1.3 to 4 ma for a collector voltage variation from -10 to +10 v. It is clear that such small voltages cannot produce appreciable variations in the trajectories of 12-kv ions. The cause of these current variations has not been definitely assigned, but they may be due in part to secondary electron emission at the collector, and in part to the existence of slow electrons and ions throughout the volume traversed by the beam. These current variations emphasize the necessity of auxiliary measurements on the beam, such as thrust or beam power measurements as discussed below.

Oscillations in the beam current were observed at frequencies around 100 kilocycles per second. The frequency suggested two possible mechanisms. It is the correct frequency for ion plasma oscillations corresponding to the average density of ions between the source and the collector. The half period of the oscillations also corresponds to the transit time of the fast ions. Some data on these oscillations are presented in Fig. 14.

**ROCKETDYNE**  
A DIVISION OF NORTH AMERICAN AVIATION, INC

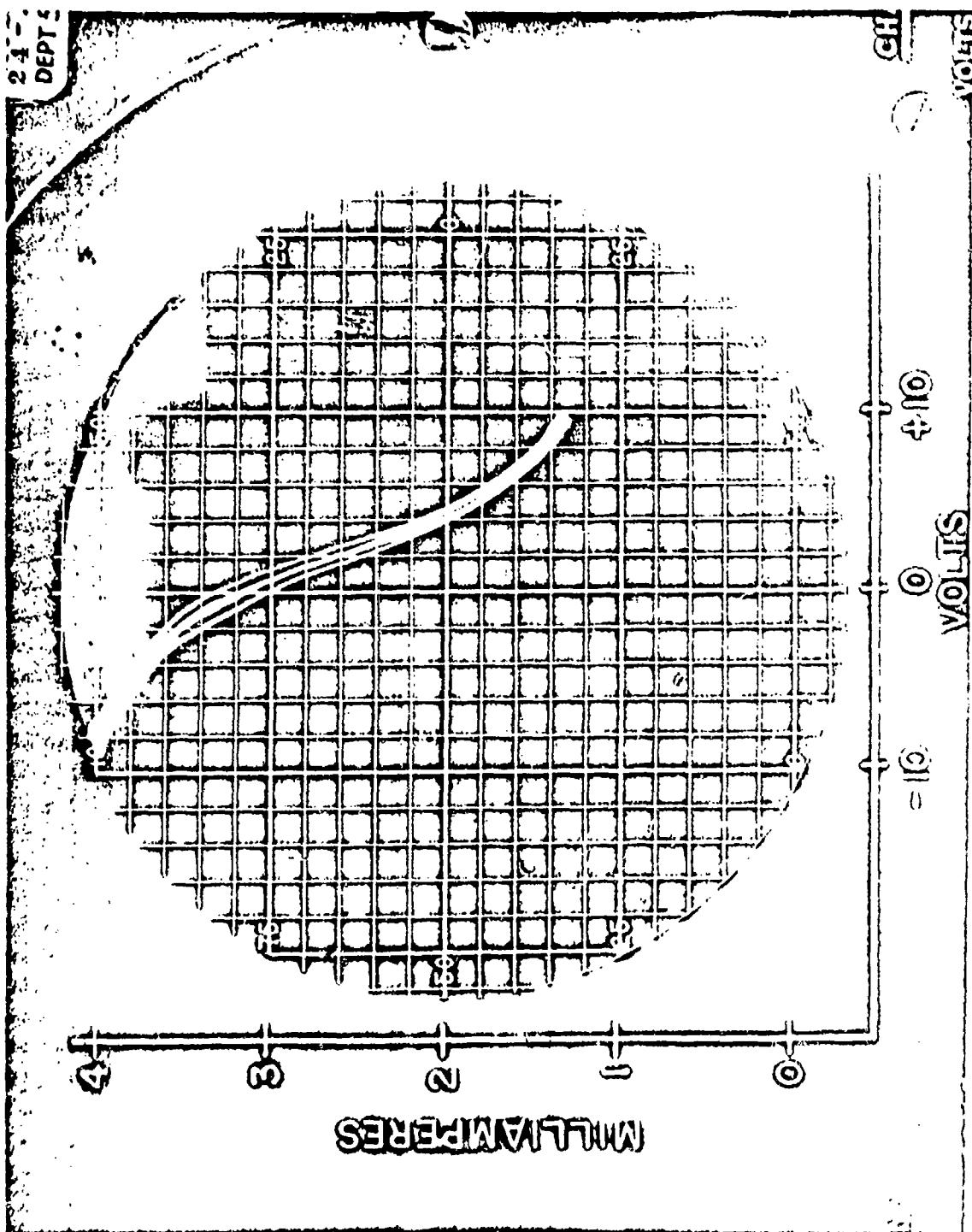


Figure 13. Collector Current vs Collector Bias

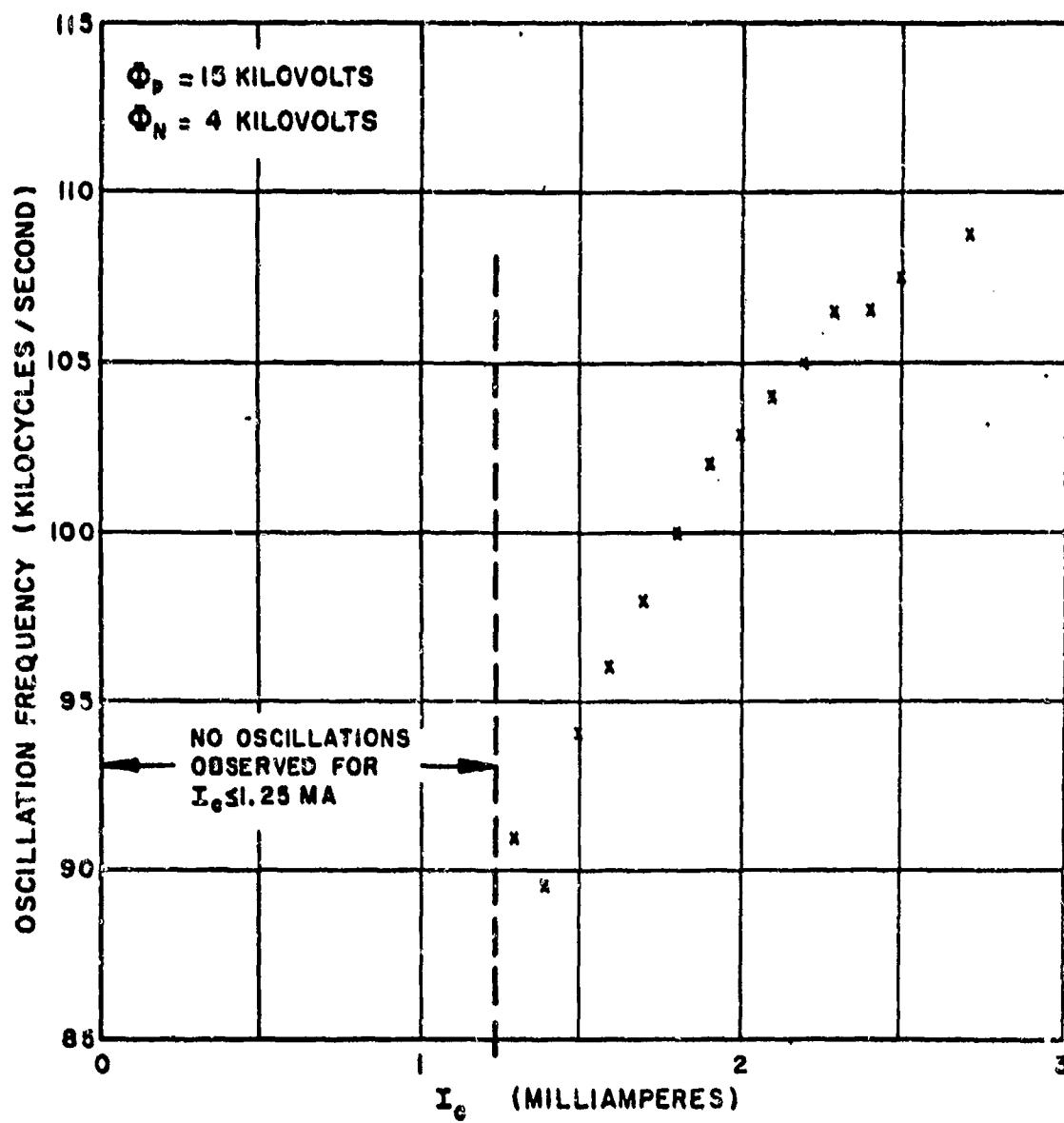


Figure 14. Oscillation Data

The oscillations could be readily quenched by raising the negative voltage on the accelerating electrode, or by allowing the pressure in the chamber to rise. Under no conditions were oscillations observed at currents less than 1.2 ma (corresponding to about  $10 \text{ ma/cm}^2$  at the source).

It is important to investigate these oscillations thoroughly and to determine whether they are inherent in this type of ion motor operation or are initiated by the test facility. If they originate in the accelerate-decelerate region, for instance, then it would be necessary to determine their effect on the efficiency and lifetime of the motor. If they are due to a cavity resonance effect, depending on the tank dimensions or the collector location, then means of eliminating their effect on other data may be found. The determination of the source of the oscillations will be pursued concurrently with other tests in future runs. A grounded fine wire grid installed in front of the collector is expected to reduce the effect of the two current variations noted on other measurements.

#### EIGHT-IN. TANK INSTRUMENTATION

Reservoir temperatures were generally observed with iron/constantan thermocouples. Ionizer temperatures were measured with a platinum/platinum-rhodium thermocouple or with an optical pyrometer where the view was unobstructed.

Measurements of the power in the beam were made by observing the temperature rise of water circulating at a measured flowrate through a copper cone in which the beam was collected (shown schematically in Fig. 2). These measurements, initially made with thermocouples, gave unsatisfactory check with zero bias collector readings, but the indications were small and response times so long that precision was poor. A much lighter cone was constructed, and the thermocouples were replaced with resistance thermometers so that high sensitivity and shorter response time are now

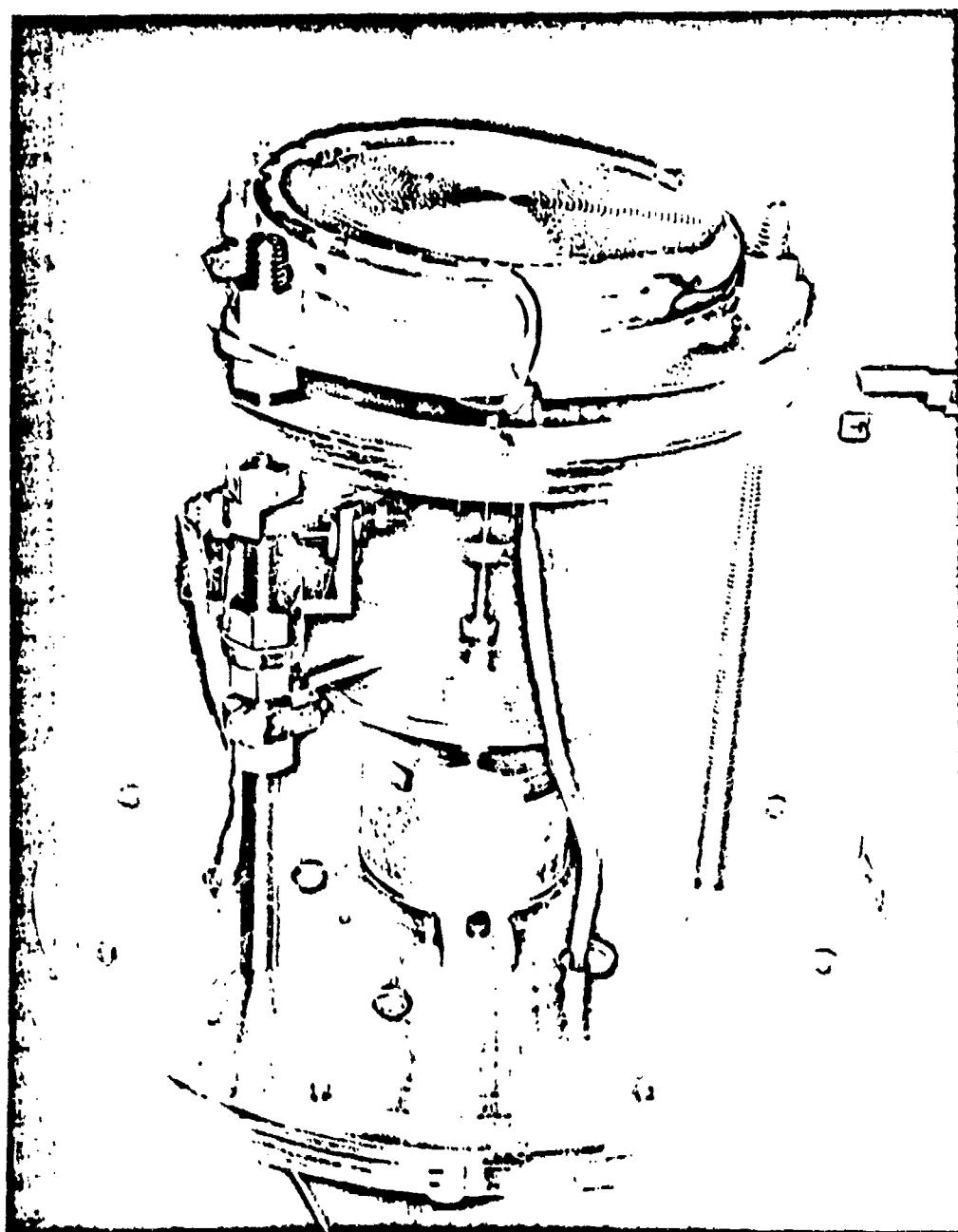
available. Calibration proved the device to be adequately linear with a sensitivity of 1/2 w in the 0- to 100-w range and an accuracy of 1/2 percent of full range. The range can be extended by reducing the resistance thermometer bridge excitation current, or the sensitivity can be improved by raising the bridge current.

The collector shown in Fig. 15 and 16 was used to measure the thrust produced by the ion beams. It consists of a grooved graphite beam-collecting plate and a capacitive displacement transducer mounted by pendulum supports with magnetic damping. For a 4 ma, 12 kv ion beam, the thrust should be 160 micropounds--far above the 10- to 20-micropound noise background of the measurement system. The thrust measurement did indicate approximately this level, but varied erratically with current and voltage. Lack of reproducibility of these measurements is attributed primarily to the oscillations previously discussed and which were discovered subsequent to the last use of the thrust measuring device. For currents of the order of 1 ma, the collector occasionally showed deflections opposite to the direction expected. This was attributed to electrostatic effects expected to be eliminated by the inclusion of the fine grounded grid in front of the collector.

#### FABRICATION TECHNIQUES

A continuous problem has been the leakproof mounting of ionizers to the cesium delivery system in such a way that their porosity was not affected. Graphite ionizers were nickel plated around their peripheries and brazed or welded into position, or, in the case of the SAMMY device, clamped in place with a platinum gasket. Nickel was heliarc welded, and tungsten was heliarc welded to molybdenum or brazed in with nickel. Currently, a spot-welding technique for mounting porous tungsten to molybdenum is being pursued.

**ROCKETDYNE**  
A DIVISION OF NORTH AMERICAN AVIATION, INC.



1 P X-28

Figure 15. Thrust Measurement Device

R-1763

94

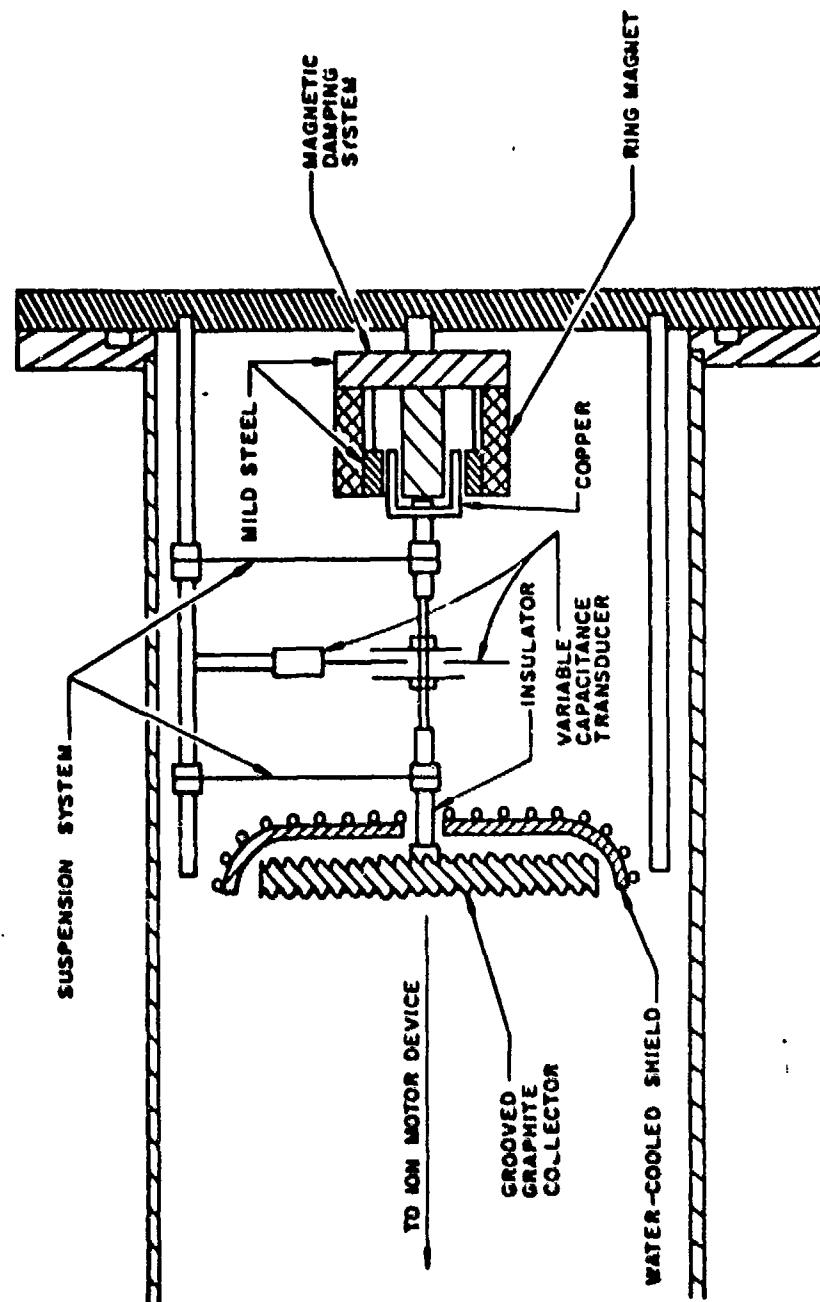


Figure 16. Schematic of Thrust Measurement Device

#### **NEUTRALIZATION**

Following the close of the period covered by this report but prior to its writing, the neutralization of an ion beam was successfully undertaken. Electrons were supplied by a thermionic emitter at the neutral electrode. The collector current measurement dropped to zero while the calorimetric power measurement which had agreed with the un-neutralized ion current measurement remained unchanged. This meant that the correct ion current was still reaching the collector, because the power delivered by the electrons would be negligible compared to that of the 12 kv energy ions. This test was made at the end of a brief run which had to be terminated because of high voltage difficulties resulting from too-close spacing of the field shaping and accelerating electrodes. More thorough testing under stable operating conditions is scheduled in the immediate future.

---

#### FUTURE WORK

During this period, it has been ascertained that current densities as large as  $30 \text{ ma/cm}^2$  can be obtained at 1500 K from a porous tungsten ionizer. This is in accord with expectations, and is more than adequate for efficient ion motor operation. There has also been evidence that the simple expedient of appropriately positioning a thermionic electron emitter is adequate for neutralization.

Several important problems remain to be attacked. It must be ascertained that the efflux of neutral cesium is small, compared to the ion efflux. For this purpose, a hot wire detector will be used. This consists of a hot tungsten wire with a suitable collimation system directed toward the source, and it detects neutral cesium atoms by ionizing them and collecting the positive ions formed. Another planned test is the comparison of the weight loss of the cesium reservoir with the total integrated current for an extended run.

Electrode geometry, beam focusing, and neutralization studies will continue with emphasis on extended and iterated ionizer configurations. Fabrication techniques are an important problem for the larger ionizers and are currently being pursued. The possibility of obtaining wire in the micron size range and of fabricating ionizers out of this wire, or of using finely etched films of tungsten, are under investigation.

ROCK ISLAND DIVISION  
A DIVISION OF NORTH AMERICAN AVIATION INC

---

---

REFERENCES

1. Langmuir, I., and Taylor, J. B.: Physical Review 44, (1933), 423.

AD-	UNCLASSIFIED	AD-	UNCLASSIFIED
AD-	<p>Rocketdyne, a Division of North American Aviation, Inc.</p> <p>SUMMARY OF EXPERIMENTAL ION ROCKET PROGRAM FOR THE PERIOD 1 MAY 1958 TO 30 APRIL 1959, by Rocketdyne Engineering, May 1959. 30 p. incl. illus. (Rocketdyne Report R-1765) AFOSR-TN-59-878</p> <p>(Contract AF 49(638)-351)</p> <p>Unclassified report</p> <p>The purpose of this program is to gain an understanding of basic electrical propulsion principles, propellant properties, and ionization and (over)</p>	<p>Rocketdyne, a Division of North American Aviation, Inc.</p> <p>SUMMARY OF EXPERIMENTAL ION BUCKET PROGRAM FOR THE PERIOD 1 MAY 1958 TO 30 APRIL 1959, by Rocketdyne Engineering, May 1959. 30 p. incl. illus. (Rocketdyne Report R-1763) AFOSR-TN-59-878</p> <p>(Contract AF 49(639)-351)</p> <p>Unclassified report</p> <p>The purpose of this program is to gain an understanding of basic electrical propulsion principles, propellant properties, and ionization and (over)</p>	<p>Rocketdyne, a Division of North American Aviation, Inc.</p> <p>SUMMARY OF EXPERIMENTAL ION ROCKET PROGRAM FOR THE PERIOD 1 MAY 1958 TO 30 APRIL 1959, by Rocketdyne Engineering, May 1959. 30 p. incl. illus. (Rocketdyne Report R-1765) AFOSR-TN-59-878</p> <p>(Contract AF 49(638)-351)</p> <p>Unclassified report</p> <p>The purpose of this program is to gain an understanding of basic electrical propulsion principles, propellant properties, and ionization and (over)</p>
AD-	<p>Rocketdyne, a Division of North American Aviation, Inc.</p> <p>SUMMARY OF EXPERIMENTAL ION ROCKET PROGRAM FOR THE PERIOD 1 MAY 1958 TO 30 APRIL 1959, by Rocketdyne Engineering, May 1959. 30 p. incl. illus. (Rocketdyne Report R-1765) AFOSR-TN-59-878</p> <p>(Contract AF 49(638)-351)</p> <p>Unclassified report</p> <p>The purpose of this program is to gain an understanding of basic electrical propulsion principles, propellant properties, and ionization and (over)</p>	<p>Rocketdyne, a Division of North American Aviation, Inc.</p> <p>SUMMARY OF EXPERIMENTAL ION ROCKET PROGRAM FOR THE PERIOD 1 MAY 1958 TO 30 APRIL 1959, by Rocketdyne Engineering, May 1959. 30 p. incl. illus. (Rocketdyne Report R-1763) AFOSR-TN-59-878</p> <p>(Contract AF 49(639)-351)</p> <p>Unclassified report</p> <p>The purpose of this program is to gain an understanding of basic electrical propulsion principles, propellant properties, and ionization and (over)</p>	<p>Rocketdyne, a Division of North American Aviation, Inc.</p> <p>SUMMARY OF EXPERIMENTAL ION ROCKET PROGRAM FOR THE PERIOD 1 MAY 1958 TO 30 APRIL 1959, by Rocketdyne Engineering, May 1959. 30 p. incl. illus. (Rocketdyne Report R-1765) AFOSR-TN-59-878</p> <p>(Contract AF 49(638)-351)</p> <p>Unclassified report</p> <p>The purpose of this program is to gain an understanding of basic electrical propulsion principles, propellant properties, and ionization and (over)</p>

D-	UNCLASSIFIED	AD-	UNCLASSIFIED
<p>Acceleration techniques. Experimental studies were performed on contact ionization ion sources, ion acceleration, and ion beam neutralization. Small research-type devices were successfully operated in ion motor configurations to verify theoretical analysis and to integrate experimental tests on components. The report discusses two types of vacuum systems: a bell jar, and a small steel tank. The tank operation proved more versatile, and two working variations of the device were built and tested. Instrumentation, fabrication, and neutralization techniques and future work are described.</p>	<p>Acceleration techniques. Experimental studies were performed on contact ionization ion sources, ion acceleration, and ion beam neutralization. Small research-type devices were successfully operated in ion motor configurations to verify theoretical analysis and to integrate experimental tests on components. The report discusses two types of vacuum systems: a bell jar, and a small steel tank. The tank operation proved more versatile, and two working variations of the device were built and tested. Instrumentation, fabrication, and neutralization techniques and future work are described.</p>	<p>Acceleration techniques. Experimental studies were performed on contact ionization ion sources, ion acceleration, and ion beam neutralization. Small research-type devices were successfully operated in ion motor configurations to verify theoretical analysis and to integrate experimental tests on components. The report discusses two types of vacuum systems: a bell jar, and a small steel tank. The tank operation proved more versatile, and two working variations of the device were built and tested. Instrumentation, fabrication, and neutralization techniques and future work are described.</p>	<p>Acceleration techniques. Experimental studies were performed on contact ionization ion sources, ion acceleration, and ion beam neutralization. Small research-type devices were successfully operated in ion motor configurations to verify theoretical analysis and to integrate experimental tests on components. The report discusses two types of vacuum systems: a bell jar, and a small steel tank. The tank operation proved more versatile, and two working variations of the device were built and tested. Instrumentation, fabrication, and neutralization techniques and future work are described.</p>